Measurement and analysis of wind loadings on rooftop photovoltaic panels – A Case Study

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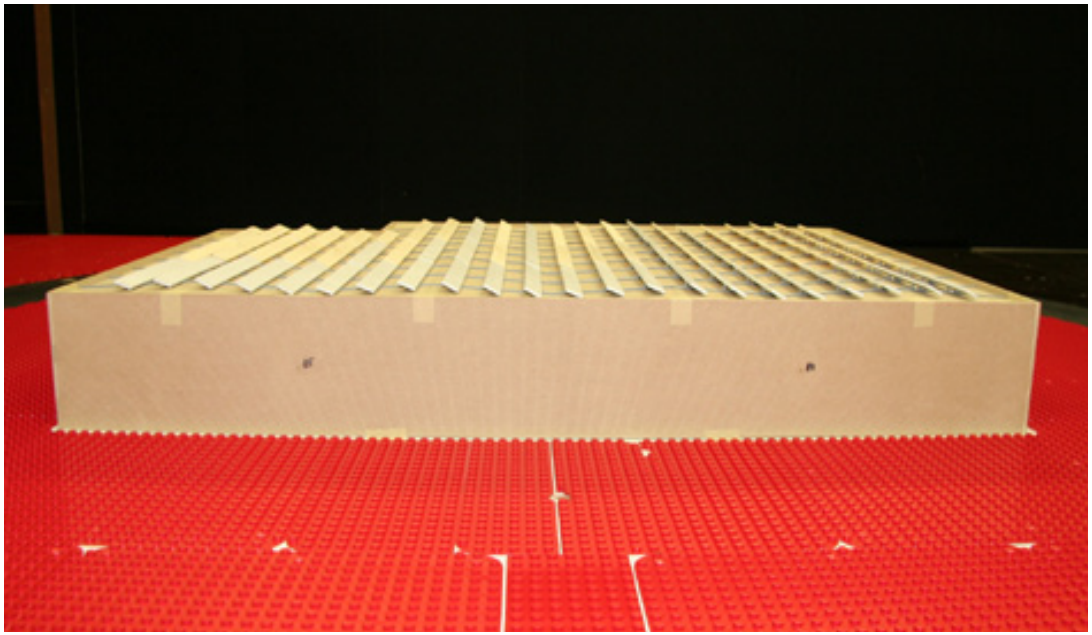
WHY: Post wind storm event

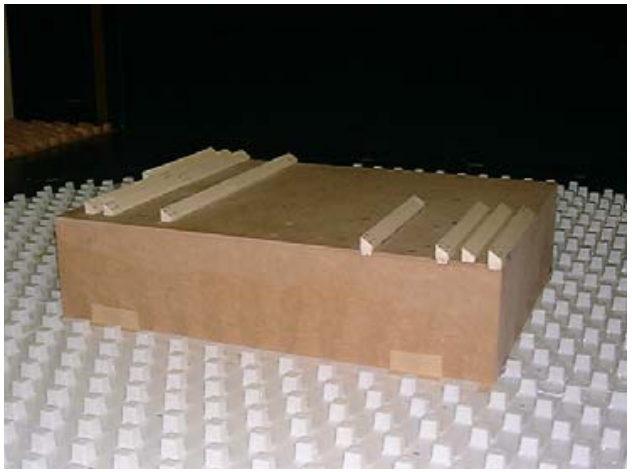
Courtesy BEW Engineering

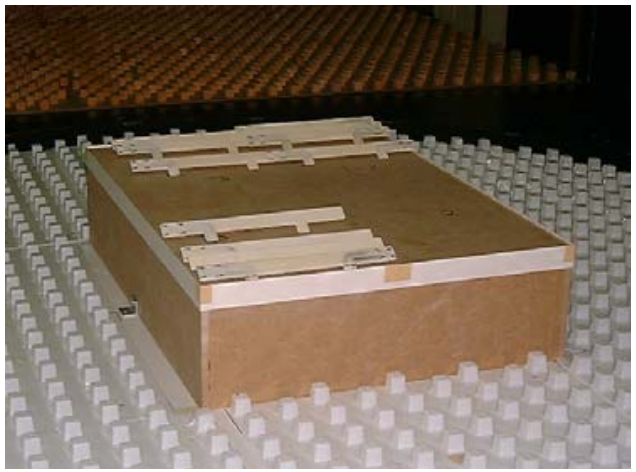
Source: SolarPro, Jun/Jul 2012, Issue 5.4

BL Wind Tunnel Studies



Source: TNO, Netherlands

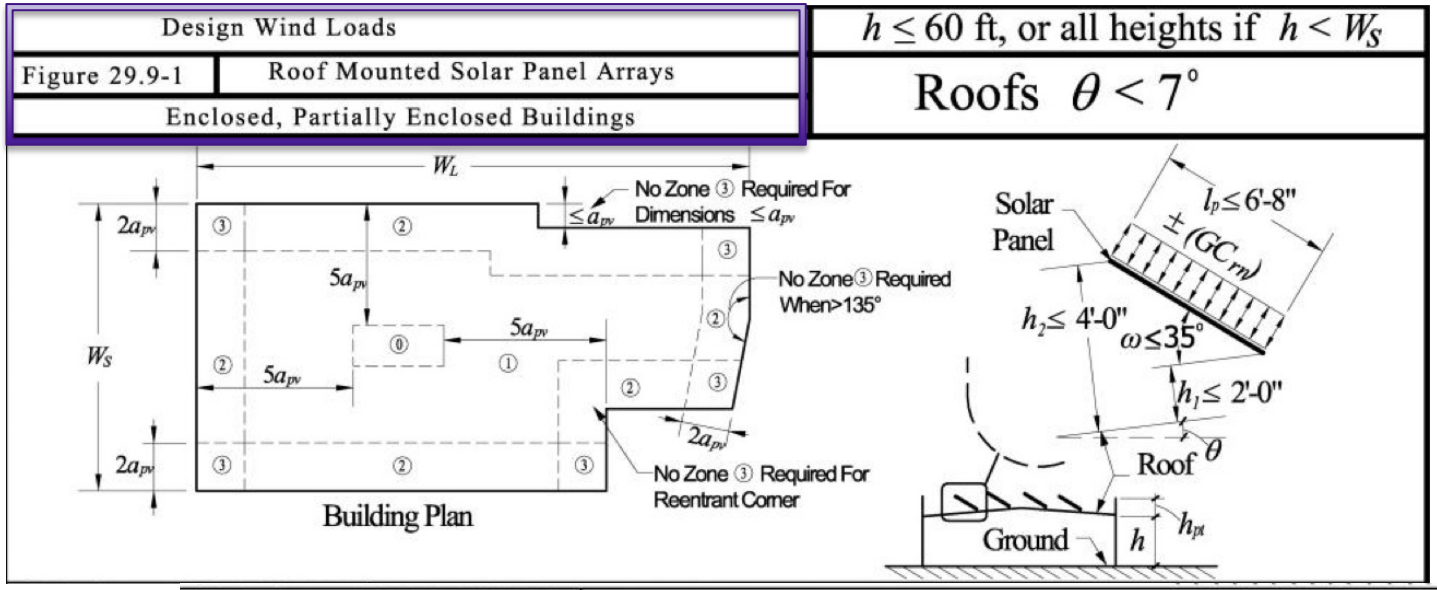




Source: Geurts & Van Bentum, TNO

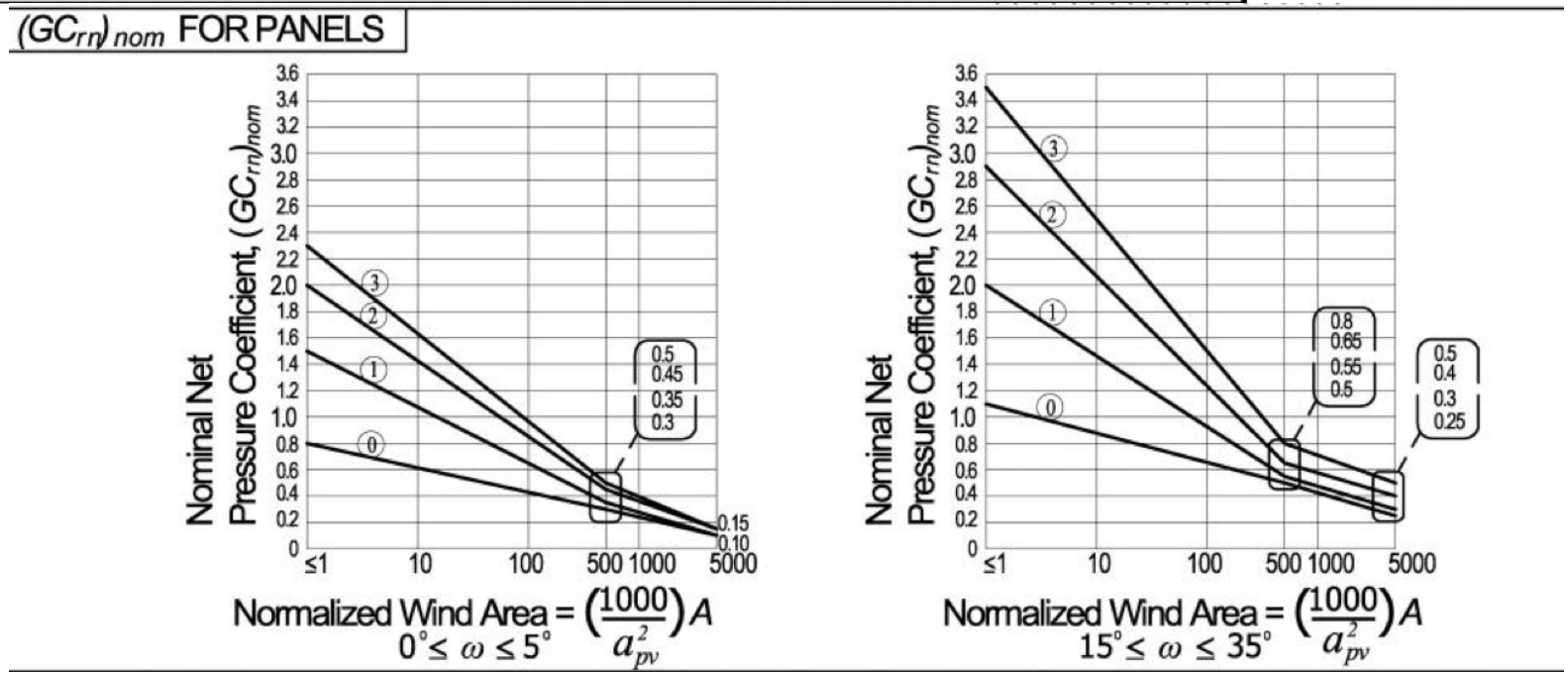
More wind tunnel tests

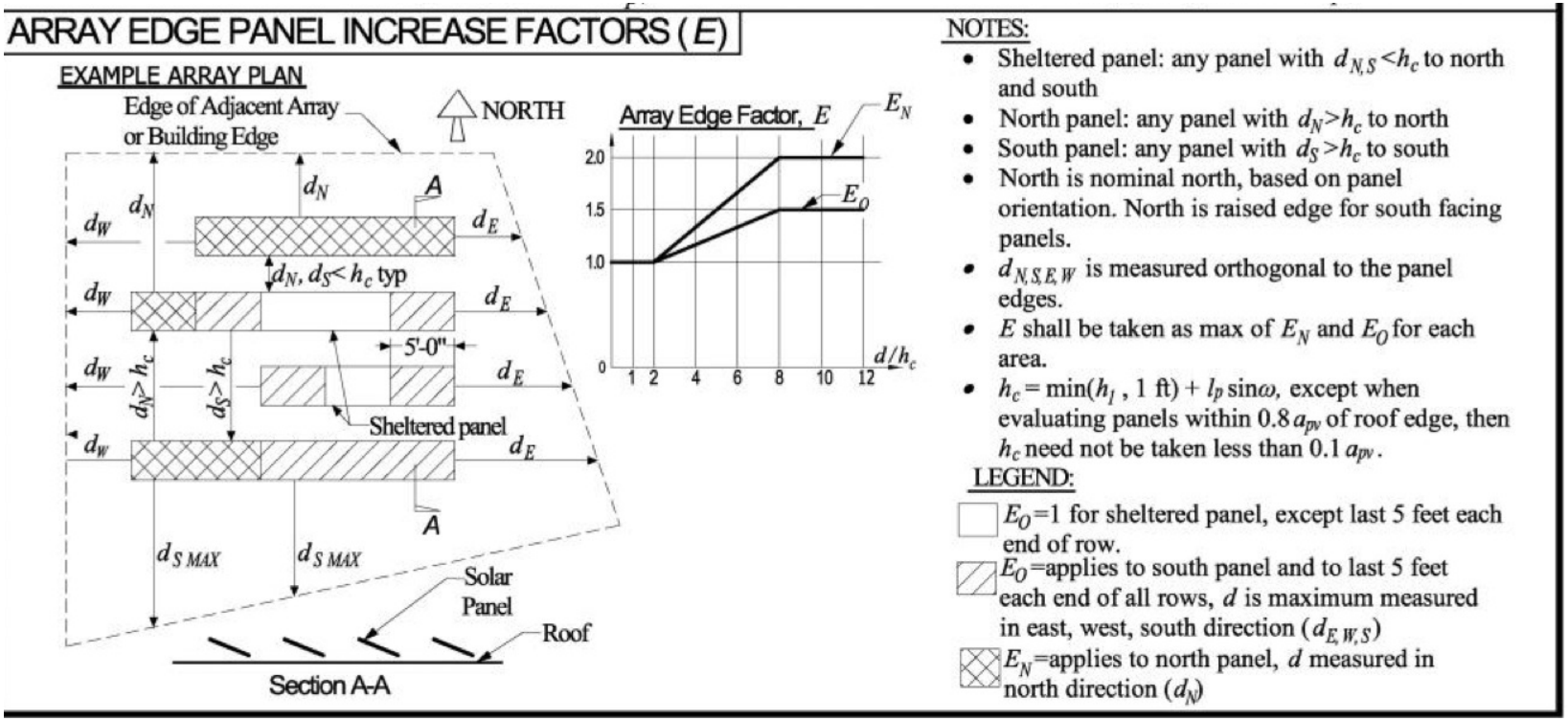
Source: Leighton Cochran, Solar Panel Report to SWEC, 2011



Result of Extensive Wind Tunnel tests

SEAOC, soon to be part of ASCE7-16





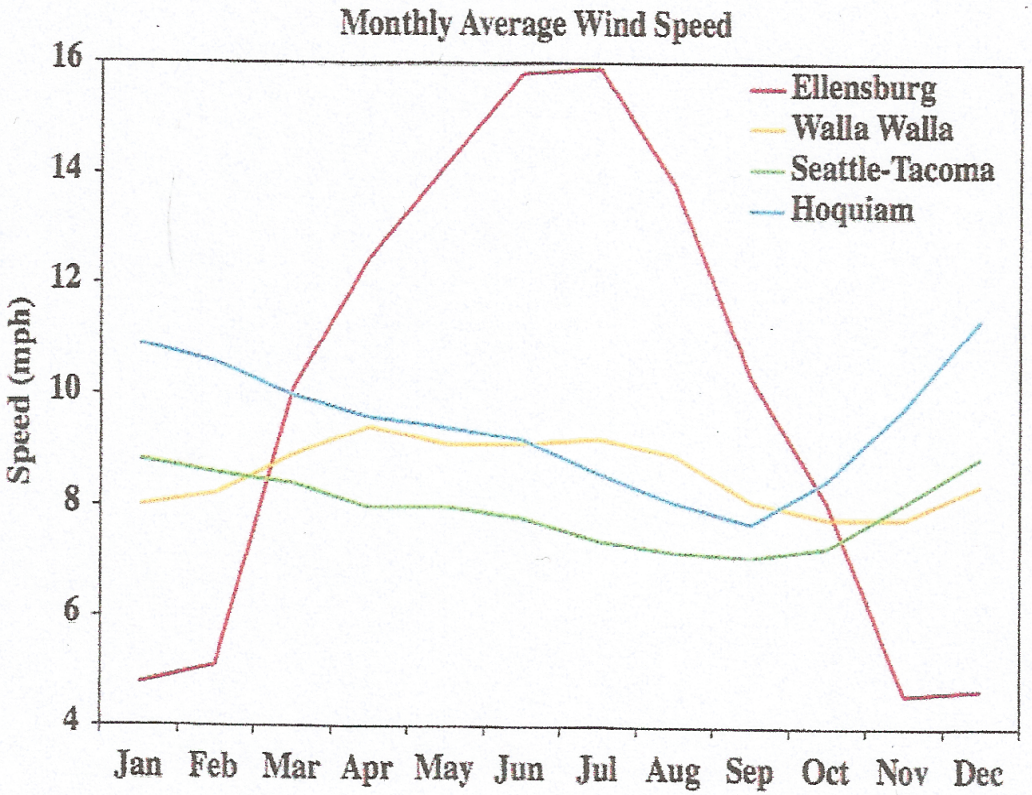
Problem solved, right?

ASCE7-16 is limited in its application to closed or low mounting systems.

Closed, low mounting system; Source: TNO, Geurts & van Bentum; HERON, Vol.52 (2007), No. 3.

Pedestal mounting system, roof, Seattle, WA.

Ellensburg, Washington is windy…



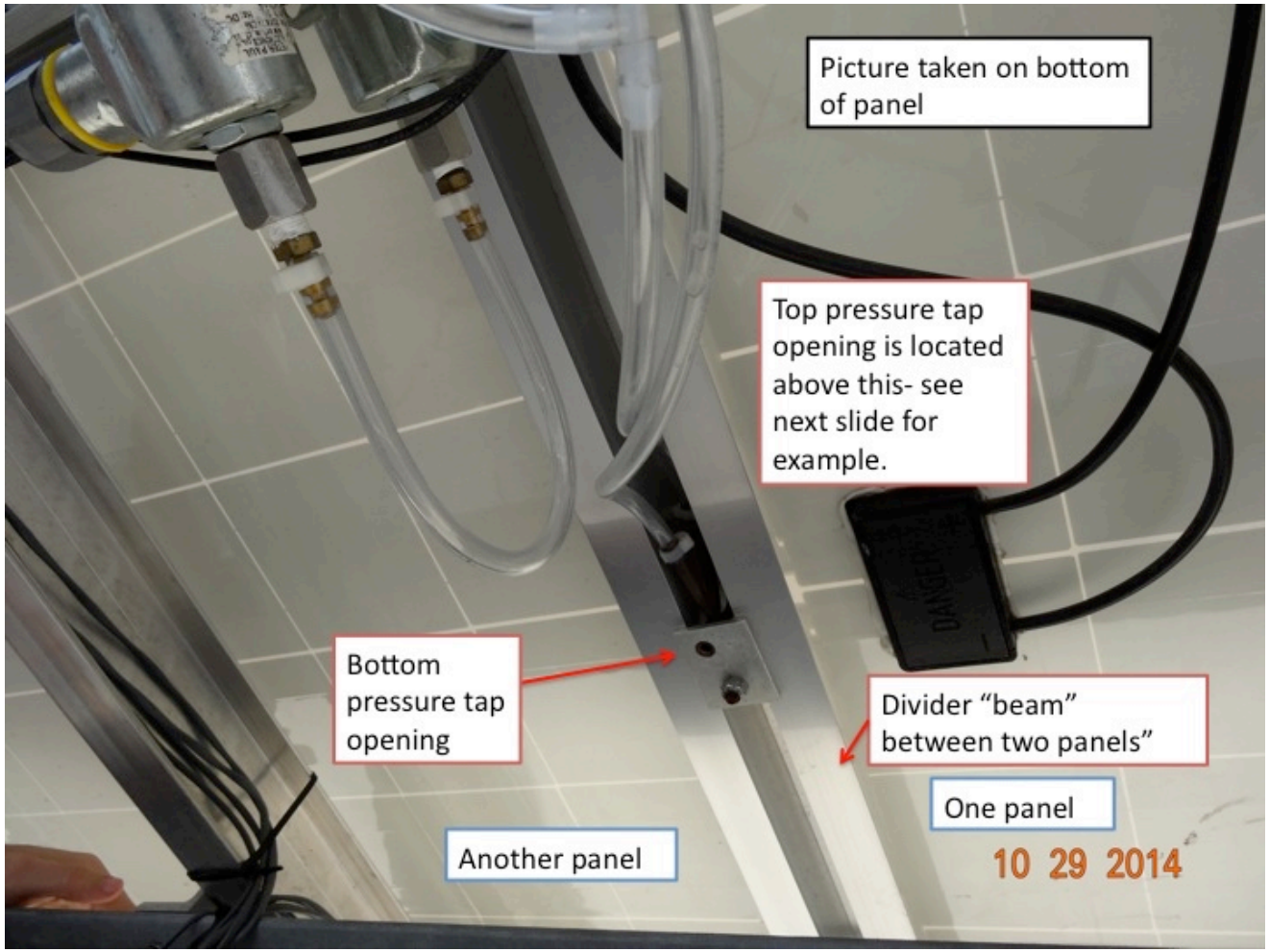
9.4. Monthly average winds (mph) at Ellensburg, Walla Walla, Seattle-Tacoma Airport, and Hoquiam, Washington. The winds are based on hourly observations for 1992-2002. Since the wind-energy potential increases with the cube of the wind speed, the Ellensburg area offers productive wind-power sites.

Source: Cliff Mass, Weather of the Pacific Northwest, UW Press.

Aerial view of Hogue. Panels are on the rooftop. N-S axes alignment within 3 degrees.

Close-up of underside of panels at the edge of the roof. Angle (fixed) is approximately 27 degrees. The measuring equipment is shown.

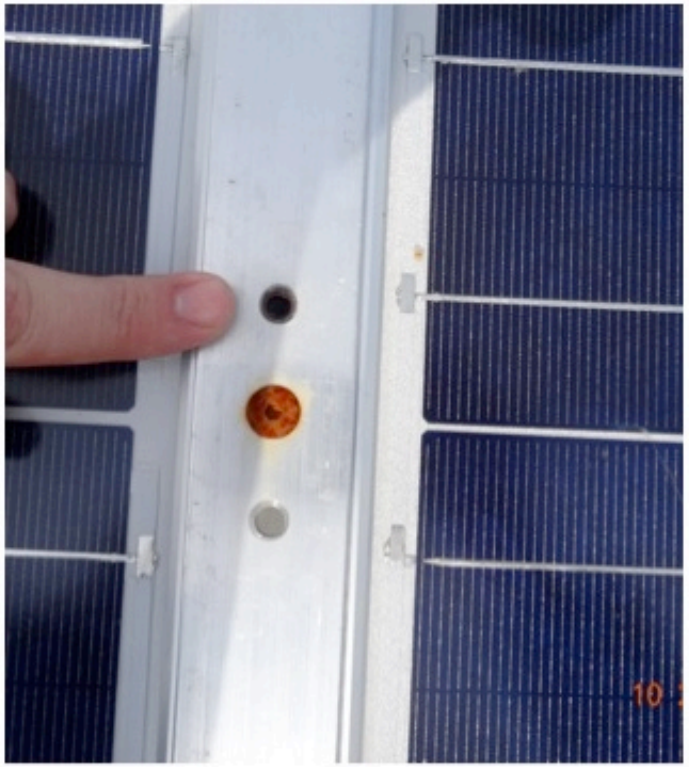
Instrumentation designed by Murray Morrison, IBHS.



Bottom of panel

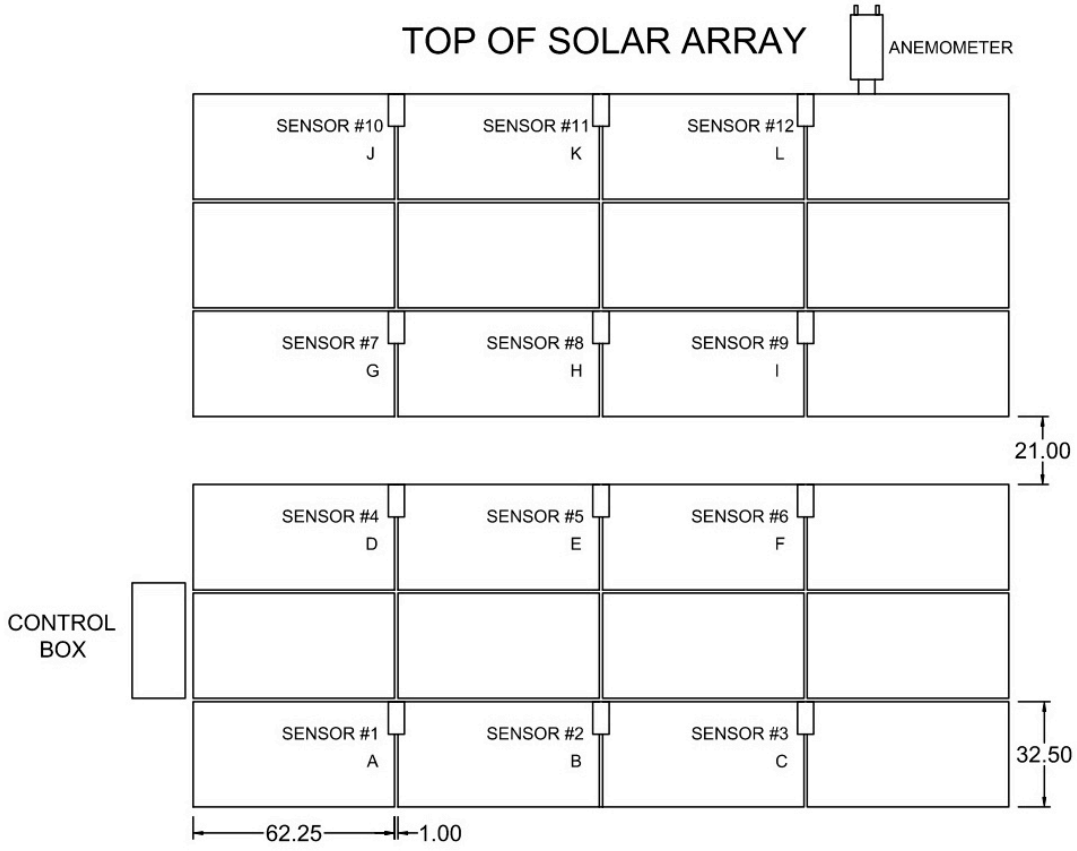
Top of panel

Top pressure openings



Set-up viewing from the rear of the panel placement as in previous slide. Note that anemometer placement is too low, so Ellensburg airport (Bowers Field) data used to examine and confirm peak wind velocity data on site.

Units in inches



Each panel is 32.5 in by 62.25 in.

Source: Dustin Waytuck (2014)

Calculation of *Cp*

$$Cp = \Delta p / 1/2 \ \rho U\hat{}2$$

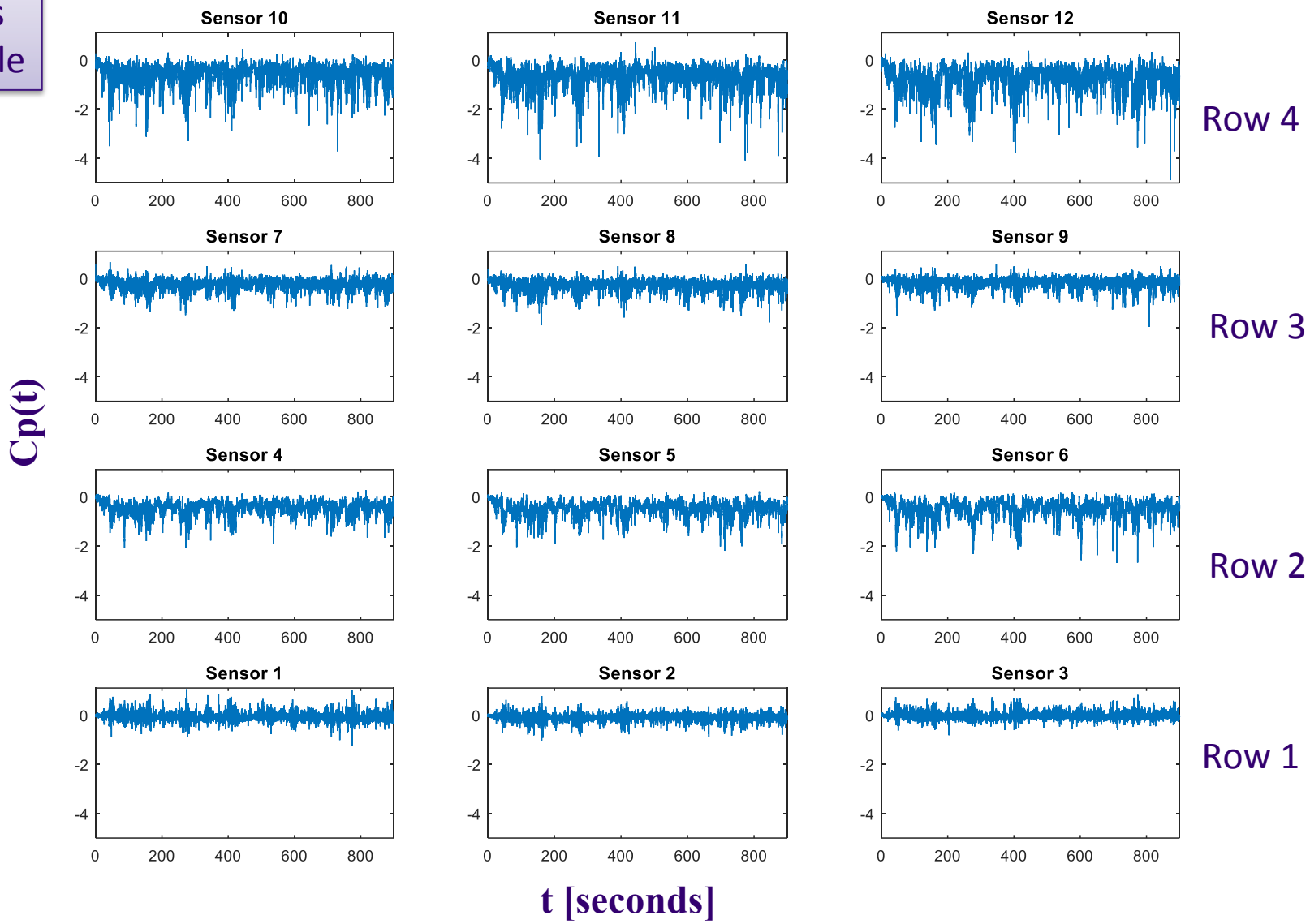
We calculated the Δp from the panel data converting from *voltage* to *psf* values.

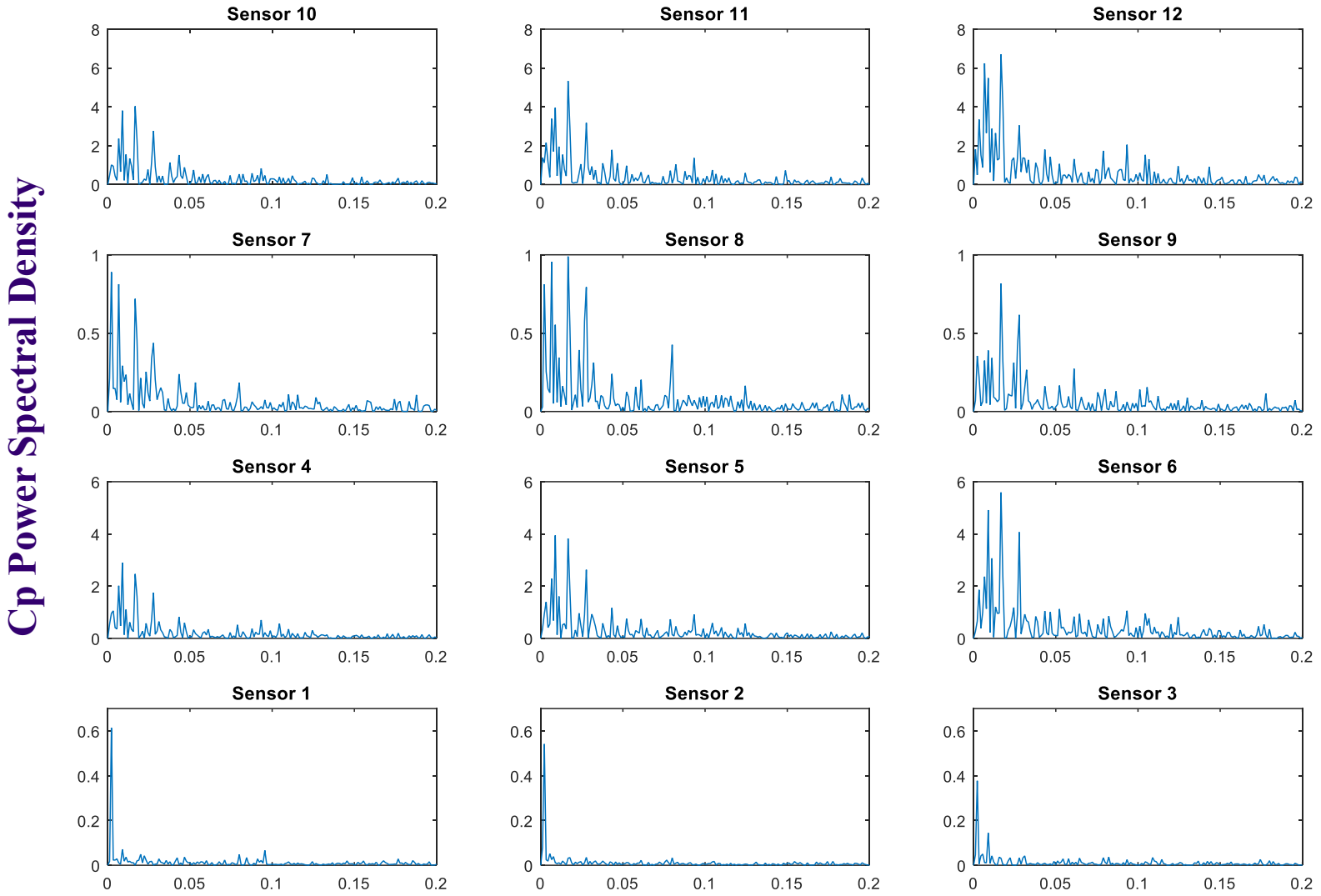
We used the mean velocity *U* at Bowers Field over 15 minutes (900 seconds) for each time series to calculate the $1/2 \ \rho U\hat{}2$.
(The density data we also calculated).

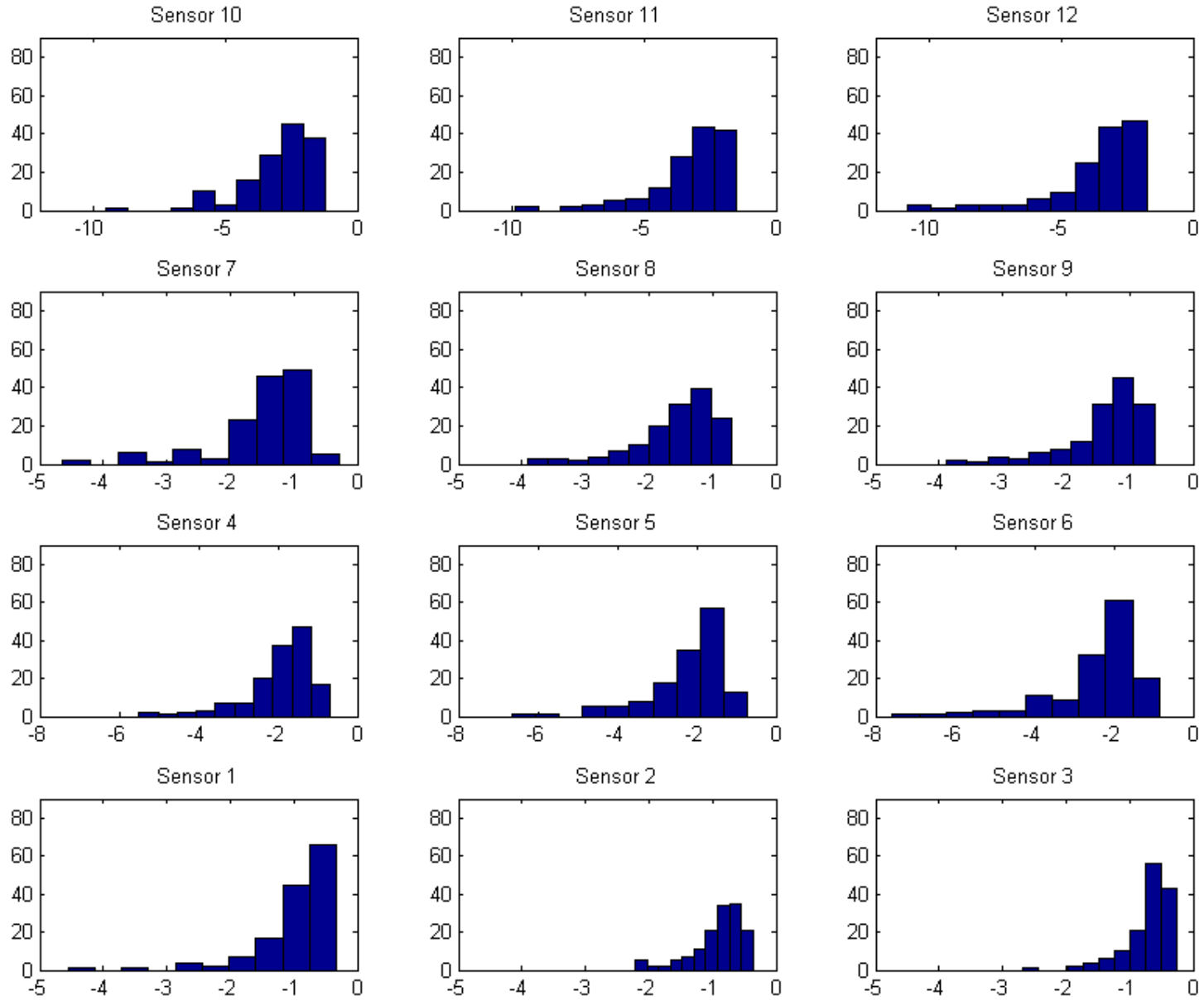
If we want to evaluate *Cp* for the 3-sec gust speed, we can use the Durst plot, which would result in dividing the *Cp* values by 2.16.
Or we can look up the recorded gust speed using the QCLCD spreadsheet data for the record time frame for nearby Bowers Field to make the conversion directly.

Time Series Example

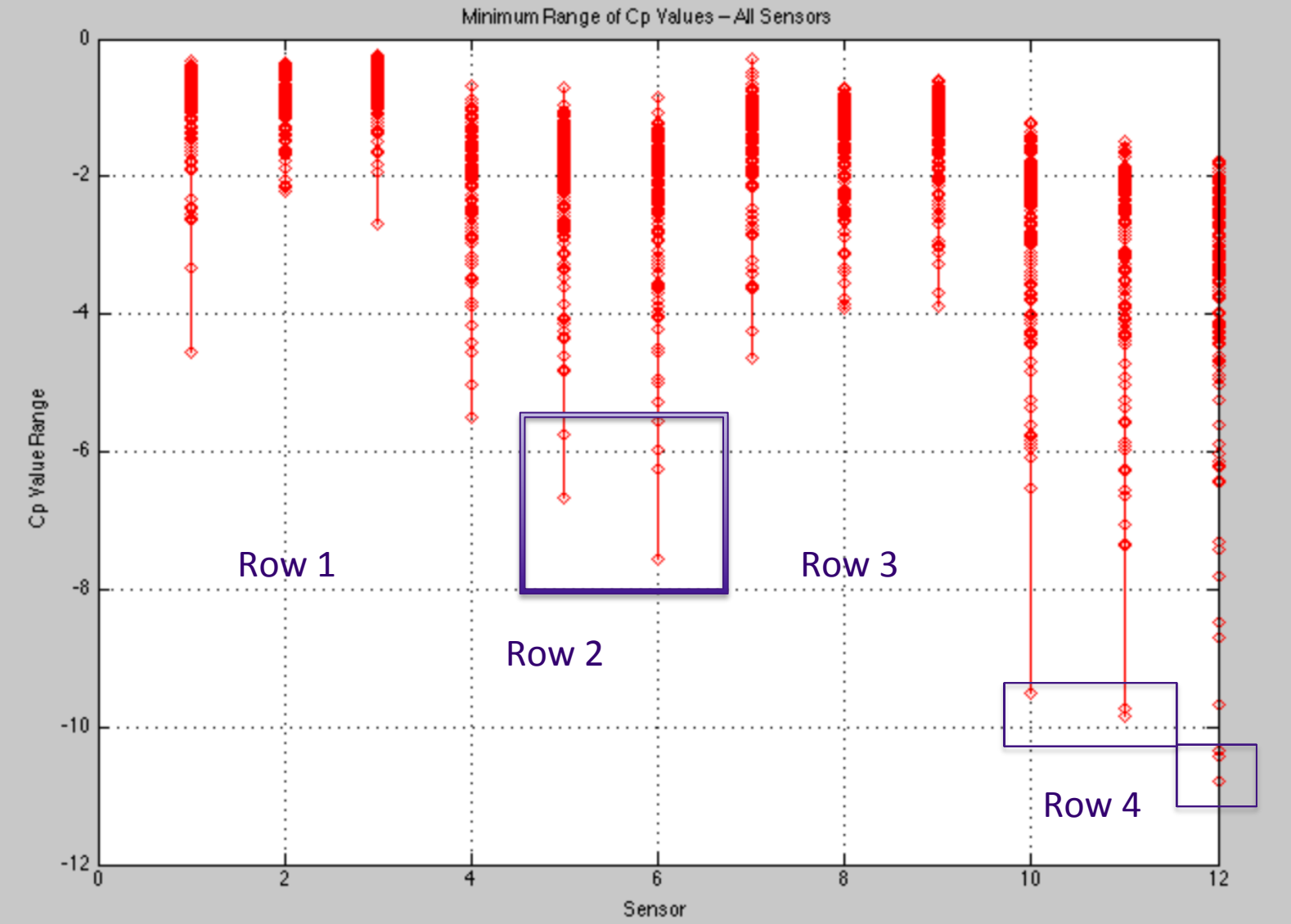
Velocity for this storm: mean = 15.5 mph [6.9 m/s]; peak is 29.5 mph [13.2 m/s].

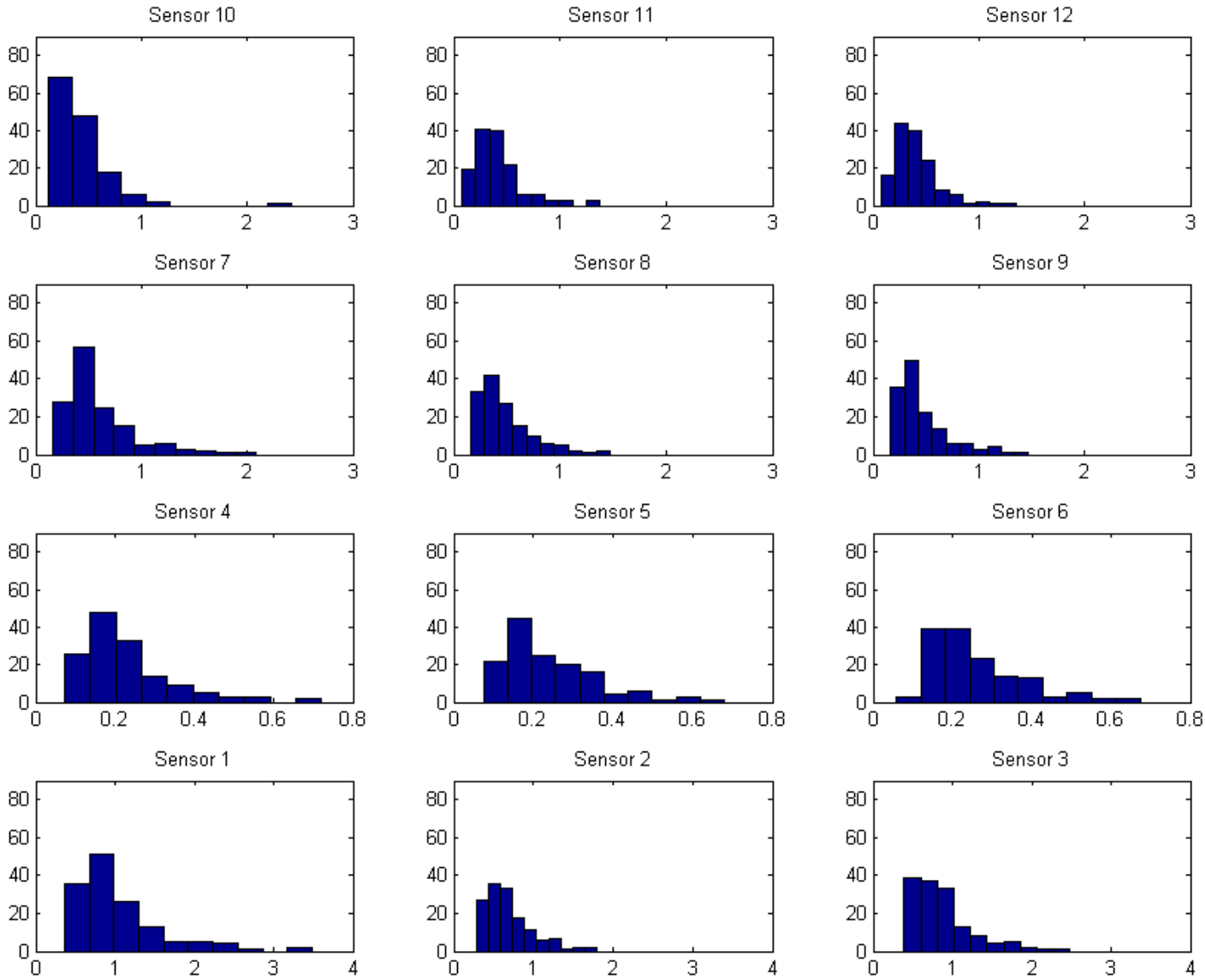


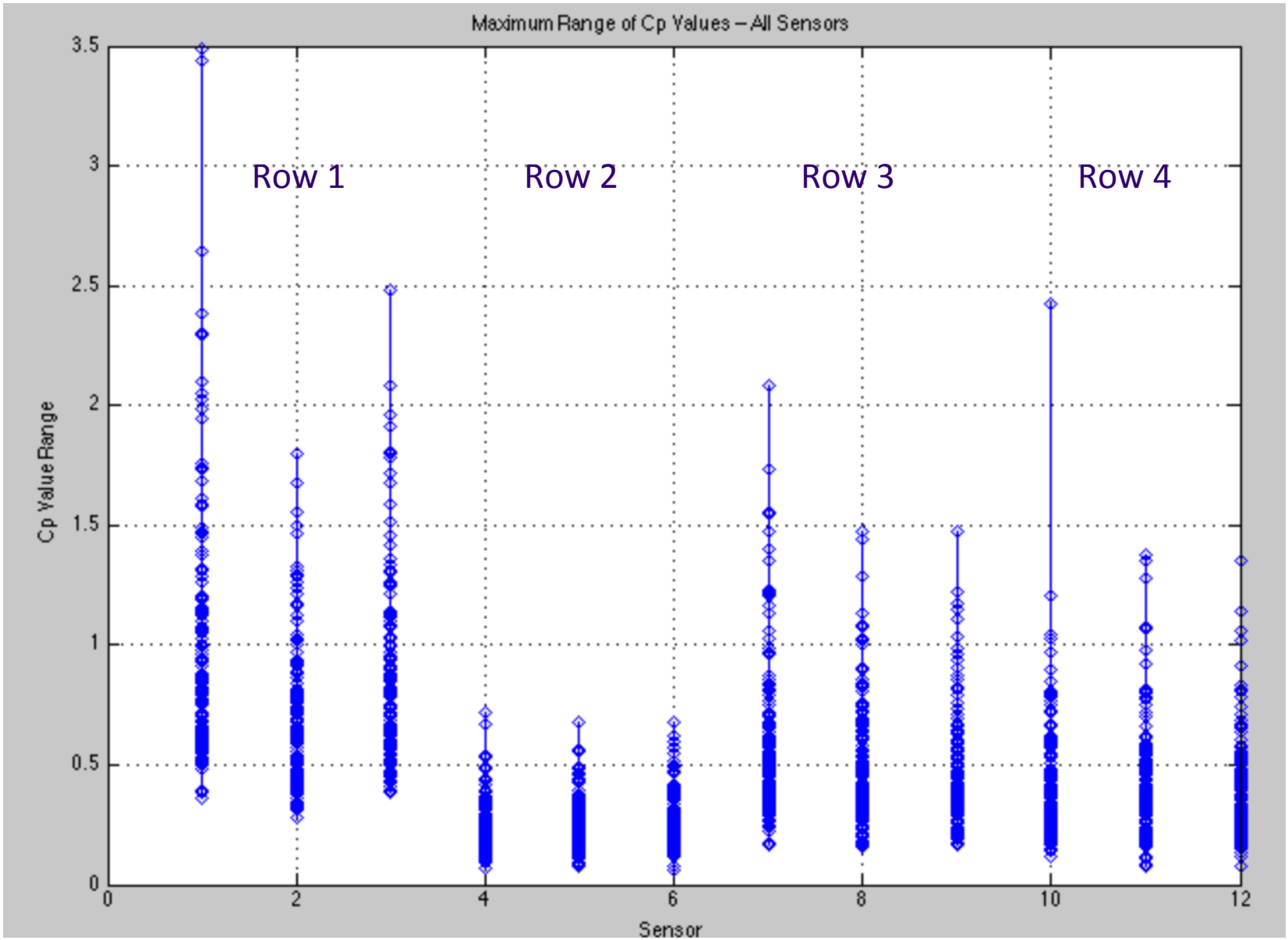

Sensor 10
Sensor 11
Sensor 12
Sensor 7
Sensor 8
Sensor 9
Sensor 4
Sensor 5
Sensor 6
Sensor 1
Sensor 2
Sensor 3
Cp Power Spectral Density
Frequency [Hz]

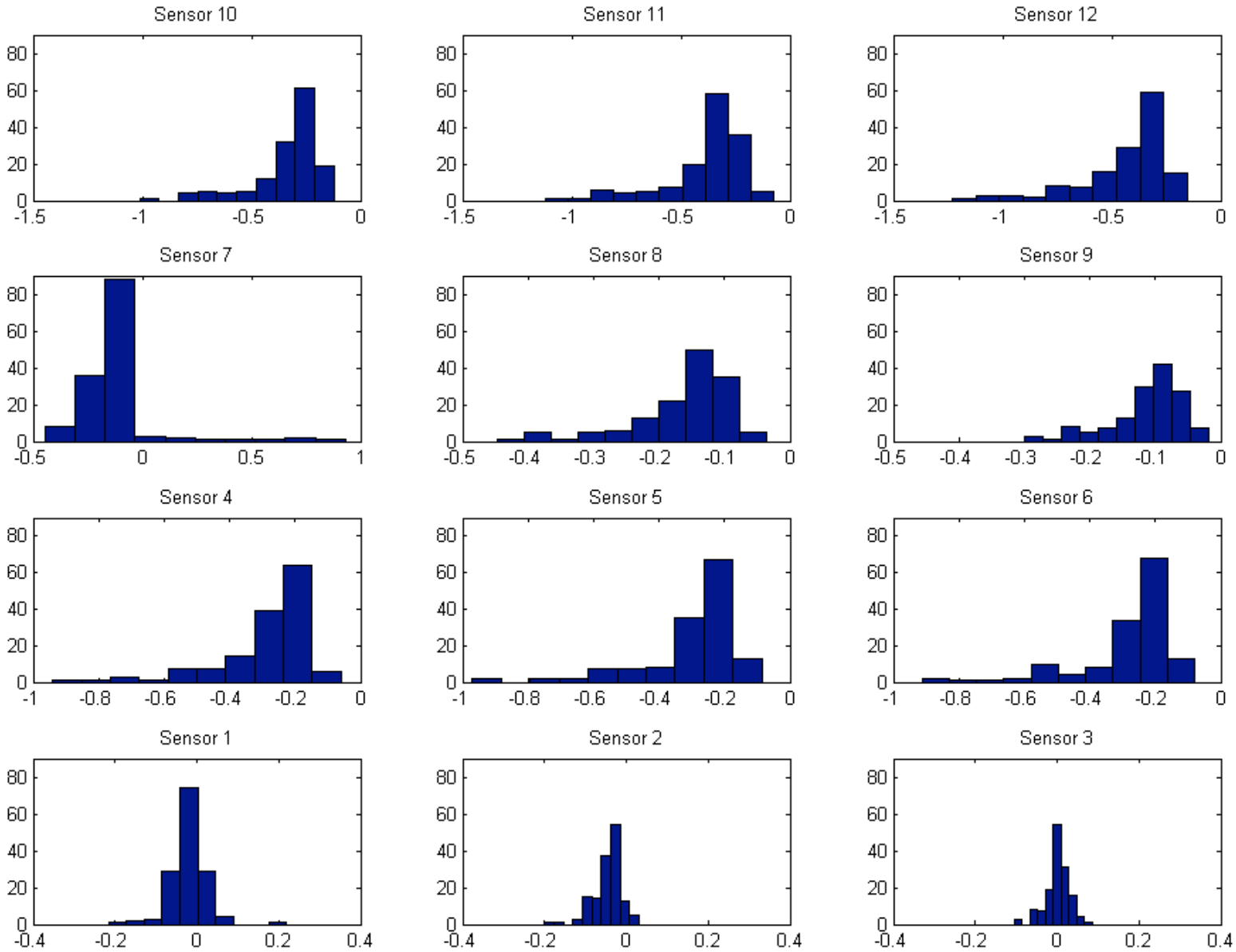

Sensor 10
Sensor 11
Sensor 12
Sensor 7
Sensor 8
Sensor 9
Sensor 4
Sensor 5
Sensor 6
Sensor 1
Sensor 2
Sensor 3
Number of observations; total =143
Cp_min values

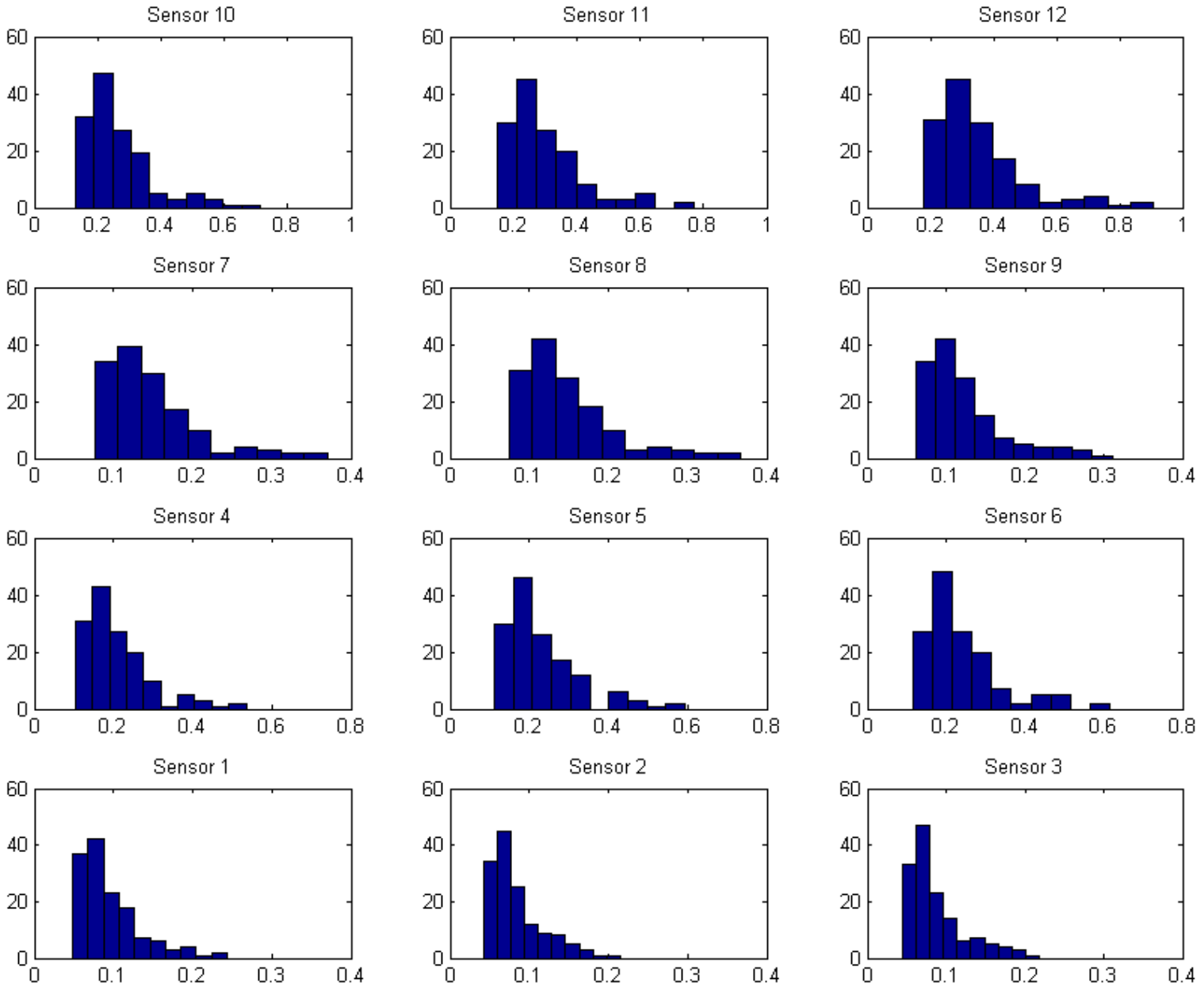
Using set of 143 records




Sensor 10
Sensor 11
Sensor 12
Sensor 7
Sensor 8
Sensor 9
Sensor 4
Sensor 5
Sensor 6
Sensor 1
Sensor 2
Sensor 3
Number of observations; total =143
Cp_max values


Maximum Range of Cp Values – All Sensors
Row 1
Row 2
Row 3
Row 4
Cp Value Range
Sensor
0
0.5
1
1.5
2
2.5
3
3.5
0
2
4
6
8
10
12


Sensor 10
Sensor 11
Sensor 12
Sensor 7
Sensor 8
Sensor 9
Sensor 4
Sensor 5
Sensor 6
Sensor 1
Sensor 2
Sensor 3
Number of observations; total =143
Cp_mean values


Sensor 10
Sensor 11
Sensor 12
Sensor 7
Sensor 8
Sensor 9
Sensor 4
Sensor 5
Sensor 6
Sensor 1
Sensor 2
Sensor 3
Number of observations; total =143
Cp_rms values

Summary & Conclusions

- Measurements were made of *Cp* values on an array of full-scale panels, in “pedestal-type” framing, near the corner of a lowrise building located in a campus setting.
- The *Cp* time series derived from the measurements are similar to those obtained for roof pressures: highly non-Gaussian. Their influence on panel strength degradation will be investigated numerically.
- The ASCE7-16 *GCrn* values are limited to single row, closed mounting systems. Given the variety of roofing conditions, and panel configurations, an expansion of the Standard in the future seems warranted.
- The relationship between the (much higher) *Cp_min* values for the panel array here and the *GCrn* values prescribed in ASCE7-16 is unclear.